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LIFE CYCLE MANAGEMENT

PIQET: the design and development of an online 'streamlined' LCA tool for sustainable packaging design decision support

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Abstract
Background, aim and scope 'Streamlined' life cycle assessment (LCA) tools hold out the possibility of providing LCA information quickly and easily in order to support a variety of decision-making environments and situations. The utility of such tools is closely related to the accuracy needs and possibilities, and the particular decisions to be supported. In order to facilitate the provision and application of LCA information in decision making during packaging design, development and utilisation, there is a prima facia case for a 'streamlined' LCA tool, provided it meets a set of requirements, including functionality, accuracy, validity, reliability and usability.
Methods One such 'streamlined' LCA tool, Packaging Impact Quick Evaluation Tool (PIQET), has been designed to allow for packaging system scenarios to be evaluated. Utilising embedded life cycle inventory data for material manufacture, converting, filling, cleaning of returnables, transport and end-of-life waste management processes, PIQET presents life cycle environmental impacts for the different levels of packaging. These life cycle environmental impacts are combined with packaging-specific indicators, such as product/packaging ratio and number of packaging materials per format, to provide the user, typically a packaging technologist, designer, environmental manager or marketer, a comprehensive assessment of the packaging format being assessed.
Results and discussion This paper introduces the case for a streamlined LCA tool for sustainable packaging design and evaluation, and describes the design and development of PIQET. Particular reference is made to the tool development model, including the involvement of industry partners' input. Goal and scope, functional unit, system boundary, characterisation and impact assessment in PIQET, and key algorithms and data sources are described. The functionality, application and limitations of the tool are also highlighted in the paper, along with ideas for further research and development.
Conclusions The paper concludes with the discussion of the inevitable trade-offs between functionality, cost and accuracy in streamlined LCA tools in comparison to more detailed and specific LCAs. The authors contend that the two approaches are not alternatives but occupy different parts of the necessary innovation niche of sustainable packaging system change. While streamlined LCA tools are compromises, they can be potentially useful and have their own unique role in furthering the use of LCA data in decision making.

Keywords Environmental impacts · Packaging · Packaging design · Packaging impact quick evaluation tool · Packaging supply chain · PIQET · Sustainability · Sustainable packaging

1 Introduction

Given the classic resource and data requirements of a 'typical' life cycle assessment (LCA), and growing needs for organisations to assess the environmental impacts of products and services, the possibility of 'streamlined' LCA tools that can provide results at fractional time and cost is immediately attractive. In addition, a more instantaneous LCA result holds out the possibility of bringing LCA-informed decision making forward in the design process,

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thus maximising the potential impact reduction and compliance with Ecologically Sustainable Design (ESD) principles (UNEP and EEA 2007; UNEP and SETAC LC Initiative 2007). However, as discussed elsewhere (Byggeth and Hochschorner 2005; Lofthouse 2006; Horne and Verghese 2009), the 'short cuts' that such tools inevitably involve in order to be quick and widely applicable can compromise their accuracy and utility; 'quick' can lead to 'quick and dirty'. Hence, any tool development endeavour must contend with the often competing needs of speed and accuracy, and devise a means of ensuring the tool meets threshold levels of performance for both criteria. Indeed, there are also other criteria that invariably need to be met in any streamlined LCA tool development process, and these may be specific to the application and planned user groups.

In this paper, the design and development process is described and discussed with particular reference to Packaging Impact Quick Evaluation Tool (PIQET)—a tool developed for a variety of stakeholders involved in the design and development of 'sustainable' packaging. The tool development model is described below, as well as the tool development criteria and functionality requirements, key algorithms and data sources, piloting, validation and commercial implementation. However, first, it is appropriate to consider briefly the context of 'sustainable packaging' and the key facets of the industry within which PIQET has been designed.

2 The role of packaging and sustainable packaging developments

Consumer packaging has been under scrutiny since the 1980s, as a potent symbol of single-use conspicuous consumption culture (Imhoff 2005). As concern builds around climate change, the drivers for packaging manufacturers, brand owners and retailers to reduce the climate impact of packaging are multiplying. These drivers typically originate with consumer concern, and are manifested through a variety of voluntary and mandatory means. Some organisations practice corporate social responsibility, while others are led by regulatory requirements, such as through the European Union Packaging and Packaging Waste Directive. In Australia, a voluntary coregulatory model exists in the form of the National Packaging Covenant (NPC) and associated requirements, including the Environmental Code of Practice for Packaging (ECoPP) (NPCC 2005). Signatories are obliged to demonstrate how they exercise and implement resource efficiency and recovery considerations, including enabling consumers to make informed decisions about consumption, use and disposal, and achieving continuous improvement in packaging performance.

In addition to the growing drivers for sustainable packaging are changes in cultural and social practices that affect the need for packaging, often in apparent conflict with sustainability drivers (Verghese 2008). This particularly applies in the case of packaging of food and beverages, which make up some 70% of the packaging applications in Australia (PCA 2005). The growing trend in the availability of prepared foodstuffs and those for consumption 'on the go', with more emphasis on individual serves, reflects rapid social change associated with 'busy' lifestyles, urbanisation and smaller household units (James et al. 2005; Pira and University of Brighton 2005). These trends, and implied growing need for packaging material, neatly illustrate the fact that packaging is necessary, and its functions include protection, containment, distribution, convenience and information. Nevertheless, while generally the food/beverage product contained within the package has a higher environmental impact than the packaging materials combined, there is a perception among consumers and policy makers that the package has significant relative impact and that less packaging (and/or more sustainable packaging) should be used. While there is currently no consensus on an agreed definition of sustainable packaging, it has been defined in Australia by the Sustainable Packaging Alliance (SPA 2002; Lewis et al. 2007) and in the USA by the Sustainable Packaging Coalition (SPC 2005). Work is also currently underway internationally to develop standard definitions and indicators for sustainable packaging (ECR Europe and EUROPEN 2009; Leahy and Polman 2009).

Retailers, who interface directly with consumers, are imposing a range of pressures upon the packaging supply chain (Verghese 2008). Their business strategies and programmes are having flow-on effects across the supply chain. For instance, as retailers increase the growth of their own-brand products, they are becoming more involved in specifying how products will be packaged. These include the use of packaging materials with recycled content, compostable materials, recyclability at end-of-life and reductions in packaging weight (Bond 2007; J Sainsbury plc 2008; Tesco 2008; Woolworths 2008a, b; Dawes 2009; Marks and Spencer 2009). There is also a range of eco-design tools, guidelines and checklists available (Envirowise 2002; INCPEN 2003; Sustainable Packaging Coalition 2006; Verghese et al. 2006; Sterling 2007; Verghese 2008; Jedlicka 2009; WRAP 2009) including the UK's WRAP Best in Class website which provides users with a benchmarking database of packaging used for food and beverages found on UK supermarket shelves (WRAP 2009). In 2007, Wal-Mart introduced the Sustainable Packaging Scorecard to evaluate the sustainability of their suppliers packaging which requires data, for instance, on greenhouse gases per unit of production, cube utilisation and product-to-packaging ratio (Wal-Mart 2007). Brand owners and packaging manufacturers are also promoting 'sustainability' programmes.

In an environment of steadily growing policies, regulations, industry programmes and consumer pressures for genuine evidence of corporate social/environmental responsibility, an ad hoc or 'wait and see' approach to packaging sustainability is increasingly exposed as insufficient to prevent rising risk to company brands and consumer confidence. As a result, there is an increasing interest in adopting a more proactive, rigorous and systematic approach to packaging sustainability. Throughout the world, companies operating in the packaging supply chain increasingly recognise the need to have systems in place whereby they can understand, calculate, monitor and better manage the life cycle impacts of their material selection, use and end-of-life waste management. Accordingly, the role of a streamlined LCA tool that combines readily available LCA data with core environmental information specifically designed for use by packaging technologists, designers, environmental managers and marketers of packaging users has been recognised by major brand owners (Horne et al. 2005; Verghese et al. 2006; Horne and Verghese 2009).

3 Outline and project design

At the inception of the PIQET project (during 2004), the authors recognised that a range of research, development, and industry practice skills and perspectives needed to be assembled. Industry input was needed in order to ensure that appropriate functionality criteria for the tool could be developed and incorporated, including efficacy, usability and practical application. In support of this aim, a partnership was set up between three Melbourne (Australia)-based organisations: the Centre for Design (CfD) at RMIT University, the Packaging and Polymer Research Unit at Victoria University and Birubi Innovation, (SPA; the Sustainable Packaging Alliance). Brand owners joined the partnership in a reference capacity both as a user group and as key actors in the emerging coregulatory environment in Australia involving decision making regarding sustainable packaging in accordance with both NPC requirements and consumer/market considerations.

The initial criteria for the PIQET project were determined as follows:

- It must have a relatively generic, nontechnical interface and feel, given its intended use by diverse actors including packaging designers, environmental managers, packaging buyers and technologists, and marketers;
- It must be possible to achieve working proficiency in 4 hours through training sessions with groups of new users;
- Multiple scenarios must be possible to enable users to run simulations, identify priority areas, set goals and targets, track progress and benchmark packaging designs over time;
- Tool utilisation should facilitate awareness building/training to inform (and challenge) existing packaging decisions and practice, in addition to providing quantitative comparisons between options;
- Packaging buyers should be able to compare/evaluate the impacts of packaging from different suppliers and use the tool to leverage changes in specifications to better meet their own sustainable packaging strategies and goals; and
- Packaging manufacturers should be able to use the tool to drive sustainable packaging innovation and advise customers, such as small medium enterprises (SMEs) without in-house packaging expertise.

SPA identified a growing need among companies in the Australian packaging supply chain, for quick and available information to be supplied on the environmental impacts of packaging material selection and design. The need to move the packaging debate from recyclability and recycling rates to include a more holistic perspective towards the role of packaging in broader societal trends such as more single households, increase in the availability and need for convenience foods, and an ageing population also highlighted the need for PIQET to assist in calculating/considering trade-offs. Retailers were also introducing shelf-ready packaging requirements that could have been driving decisions towards unsustainable practices.

The project methodology described below covers the initial development of PIQET over the period 2004–2007 and the subsequent upgrades to PIQET (2008–2009), and included the following key activities:

- *Establishment of Industry Advisory Committee (IAC)*: The PIQET project was designed so that the research team was actively involved with potential users from the start of the project. Packaging technologists and environmental managers representing a selection of food and beverage manufacturers and brand owners were approached in mid-2004, as they were the key personnel responsible for packaging design decisions and environmental reporting for the NPC. The IAC, who met every 3–4 months, operated as an open forum, whereby the research team presented current designs and progress of the tool, with the IAC invited to provide feedback. This was the forum where functionality requirements were also identified and prioritised.
- *Literature review:* Involved the assessment of other tools that were being used in 2004–2005 (e.g. online Tool for environmental Optimisation of Packaging design (TOP), BASF eco-efficiency tool, BRIDGESworks Metrics, MERGE) and found they varied in their operation (e.g. manual checklists through to software programs), their coverage (e.g. life cycle stages, compliance with EU

Directive on Packaging and Packaging Waste), cost (i.e. free through to expensive), relevance, availability and turnaround times. These tools, at the time, were either too simplistic or were not tailored specifically for packaging (Verghese et al. 2006).[1]

- *Classification of packaging levels:* There are usually differences in terminology on how different companies and industry sectors would classify packaging units. *Primary packaging* is any packaging in contact with product, i.e. sub-retail and/or retail unit; *secondary packaging* is the merchandising unit, and *tertiary packaging* is the traded unit as well as the pallet unit. In PIQET, the terminology adopted to categorise different packaging levels is presented in Fig. 1.
- *Development of system boundary:* PIQET was designed to enable the assessment of all levels of packaging on a fully packed pallet sent from the filler to a retailer and its final disposal. The scope of assessment of packaging system boundary in PIQET is "cradle-to-grave" and includes the following life cycle phases for a packaging component: raw material production, material conversion, transport of packaging material to filler, filling of packaging, transport of packed product to retailer, return transport to filler for returnable packaging, cleaning for returnable packaging and end-of-life waste management (includes landfill, recycling, incineration with energy recovery, incineration without energy recovery and composting).

  Notably, excluded from the system boundary were the processes involved in the product life cycle (the substance contained within the packaging). It was understood that, in many cases, the interaction between the packaging life cycle and the product life cycle would be likely to contribute to environmental impacts (such as the impact packaging has on product shelf life and wastage); however, these processes were excluded in order to simplify analysis of the packaging system.
- *Functional requirements*: A range of functional requirements was defined for the tool in order for it to be attractive, easily accessible and streamlined. These included online access and use; quick turnaround times (less than 20 min to undertake an assessment); limited information input by user with use of default values; life cycle assessment based; comparative assessment of packaging systems using scenarios in PIQET; and user-friendly report generation in PDF format highlighting life cycle impact results of selected scenarios, and reporting packaging specific indicators (Table 1) and benchmarking ability on total packaging system and individual components.

[1] Other packaging tools have been released since PIQET was commercialised in 2008. These tools include COMPASS by SPC (2009) and Pack-In by Envirowise (2009) which were both publically released in 2009.

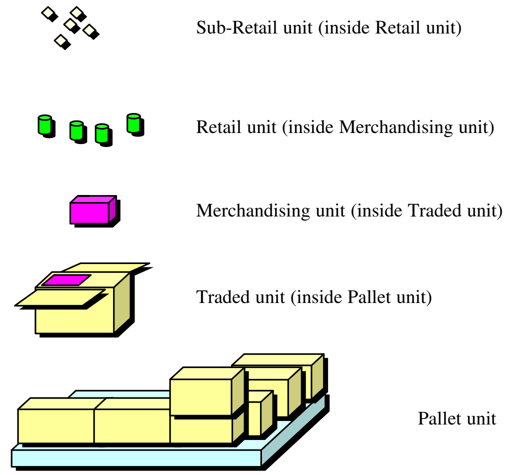


Fig. 1 Standardised packaging format levels used in PIQET

- *Development of impact assessment methodology:* The Australian impact assessment method developed by CfD has been used in PIQET. The Australian impact assessment method has been developed using a mix of characterisation factors from the Leiden University-Institute of Environmental Sciences (CML) Impact Assessment Model and from the Eco-Indicators impact assessment method. The environmental impacts included in PIQET are presented in Table 2. A discussion of the methodology is presented in Section 4. The indicators were selected in accordance with the following criteria:

- Meaningful—Indicators had to readily translate into meaningful measures that a broad audience could quickly conceptualise.
- Holistic environmental impacts—Metrics selected had to cover a wide enough range of issues to allow a comprehensive picture of environmental impact to be conveyed.
- Data availability—Data for indicators selected had to be readily available.
- Industry comparable—Measures used needed to be consistent with LCA measures used worldwide, to allow ready comparability of outcomes.
- No more than necessary—An effort was made to keep indictor types to a minimum to reduce complexity of result interpretation.

- *Use of SimaPro:* The background life cycle inventory data was modelled in SimaPro, and aggregated characterisation values for the different life cycle stages are drawn upon to calculate the resulting graphs and tables (see Section 4 for more discussion, in particular Figs. 4 and 5).

Table 1 Examples of packaging-specific indicators reported in PIQET

Product/packaging ratio; Packaging to landfill as a % and kg; Packaging to recycle as a % and kg; % recycled content of packaging per pallet load; Mass of packaging recyclable;	Kg and % of packaging per packaging level (subretail, retail, merchandising, traded and pallet); Packaging material summary (number of each individual packaging material in packaging system format).

- *Proof of concept (in MS Excel):* The first version of PIQET was designed with the MS Excel program as it allowed for easy programming of the tool to demonstrate the proof of concept (completed September 2006). The sponsoring companies road-tested the MS Excel version over several months, and this gave the research team the opportunity to receive feedback on the tool's functionalities, etc. This proved invaluable as it gave the research team the chance to quickly make amendments and send out the next revision with short turnaround time. The feedback was then used to make small amendments before detailed programming was undertaken for the web portal version of the tool (see below).
- *Web portal final product*: The first web-based version of PIQET was completed in late 2007 using the algorithms developed and road-tested in the MS Excel version of the tool. WSP Environmental undertook the web programming. PIQET was publically launched in March 2008. Companies wishing to use PIQET can purchase annual subscriptions or can access services provided by SPA.

4 Research and development

An objective of PIQET was to provide users with the capability to assess packaging system designs from a life

Table 2 Life cycle environmental impact indicators reported in PIQET

Indicator	Unit	Description
Climate change	kg CO_2 eq	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other global warming gases into the atmosphere—this indicator is represented in CO_2 equivalents. Factors applied to convert greenhouse gas emissions into CO_2 equivalents emissions conform to the 1996 Kyoto Protocol (Houghton et al. 1996). Those factors are still applied in all official reporting on greenhouse gases emissions, despite the implementation of new factors by the IPCC (Solomon et al. 2007).
Cumulative energy demand	MJ LHV	All energy use including fossil, renewable, and nuclear energy are taken into account, including feedstock (energy incorporated into materials such as plastic). The energy indicator has been designed on the basis on the first CML impact assessment method (Heijungs et al. 1992a, b).
Minerals and fuels	MJ surplus	The additional energy required to extract mineral and fossil fuel resources due to depletion of reserves, leaving lower quality reserves behind. The minerals and fossil fuel indicator has been designed from the Eco-Indicator impact assessment method (Goedkoop and Spriensma 2001).
Photochemical oxidation	kg C_2 H_4 eq	Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NO_x), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone. Factors applied to convert emissions into C_2H_4 equivalents are taken from the CML impact assessment method from 2000 (Guinée et al. 2001).
Eutrophication	kg PO_4^{3-} eq	Eutrophication is the release of nutrients (mainly phosphorous and nitrogen) into land and water systems, altering biotopes, and potentially increasing algal growth and causing related toxic effects. Factors applied to convert emissions into PO_4^{3-} equivalents are taken from the CML impact assessment method from 2000 (Guinée et al. 2001).
Land use	Ha*a	Total exclusive use of land for a given time for occupation by the built environment, forestry production and agricultural production processes. This indicator is mostly used to have a measure of the impact on biodiversity. Most of the data are similar to the CML impact assessment method from 2000 (Guinée et al. 2001).
Water use	kL H_2O	Total of all water used by the processes considered, except turbine water used in hydro generation of electricity.
Solid waste	kg	Total of all solid waste generated by the processes considered. This indicator has been designed according to the first CML impact assessment method (Heijungs et al. 1992a, b). Note that the CML 92 is the only European impact assessment method that takes solid waste into account.

cycle perspective, quickly and with a minimum technical training. In striving to achieve this goal, ISO14040 was applied as the guiding standard method in designing the tool architecture to undertake packaging system assessment. At the onset, it was acknowledged that a wide variety of software packages currently existed which facilitate LCA. PIQET is designed specifically for packaging systems assessment. In developing the PIQET LCA methodology, the key components of LCA were applied, as outlined below.

4.1 Goal and scope

The initial goal of the PIQET LCA was to determine the potential environmental impacts associated with the packaging system of a packaged consumer product. Narrowing the scope of the goal to packaged consumer products enabled a standardisation of the approach to be undertaken, and this simplified data requirements. Through discussions with the IAC, a functional unit and system boundary for the PIQET LCA were defined that could be applied to the majority of packaging design situations in the consumer food marketplace. As the concept of PIQET has been proven, the tool can be used for the assessment of a wide range of packaged items.

The initial geographical coverage set for the tool was Australia. The PIQET tool has subsequently been upgraded in 2009 to include the following countries/regions in addition to Australia: China, Japan, New Zealand, USA and Western Europe.

The technology and time coverage of the supporting data in PIQET for a particular country were governed by the data availability and quality. The first preference was to select reliable and publicly available data for a country. In the first version of PIQET, the Australian datasets were selected from the Australian Life Cycle Inventory (LCI) database developed at the Centre for Design at RMIT University. In case of nonavailability of Australian-specific data for a material or process, the most recent dataset was selected from other LCI databases such as Ecoinvent, IVAM, IDEAMAT, ETH-ESU 976 and BUWAL. If the dataset from other databases was available as a unit process data, the dataset was modified to represent Australian background energy data.

In the most recent upgrade of PIQET (2009) where the primary objective was to add LCI data for other countries, no reliable and publicly available data were found for China, Japan and New Zealand. In case of the USA, the coverage of datasets in the USLCI database for inclusion in PIQET was relatively thin, and certain datasets were incomplete. For Western Europe, the datasets in the Ecoinvent LCI database met PIQET's requirements of consistency, representativeness and quality. However, to ensure interregional consistency in PIQET, the following preference hierarchy was adopted:

- Australian Unit Process;
- Ecoinvent Unit Process;
- Australian or Ecoinvent System Process;
    - ○ Time period; and
    - ○ Applicability to PIQET.

For a particular country or region, the first preference was to select an Australian Unit Process data that were then customised with the regional background energy dataset. The second preference was the Ecoinvent Unit Process data. In case neither Australian nor Ecoinvent Unit Process data were available, the preference was to select an Australian or Ecoinvent System Process data, whichever were of more recent time frame and applicability for the intended material or process in PIQET. In summary, it can be stated the time coverage of the data represented in PIQET ranges from mid-1990s to present.

4.2 Functional unit

The functional unit selected for analysis in PIQET is a kilogram of product on a pallet (packed, including the packaging end-of-life) delivered to a retailer. For each kilogram of packaged product delivered, the environmental impacts of the complete packaging system are determined.

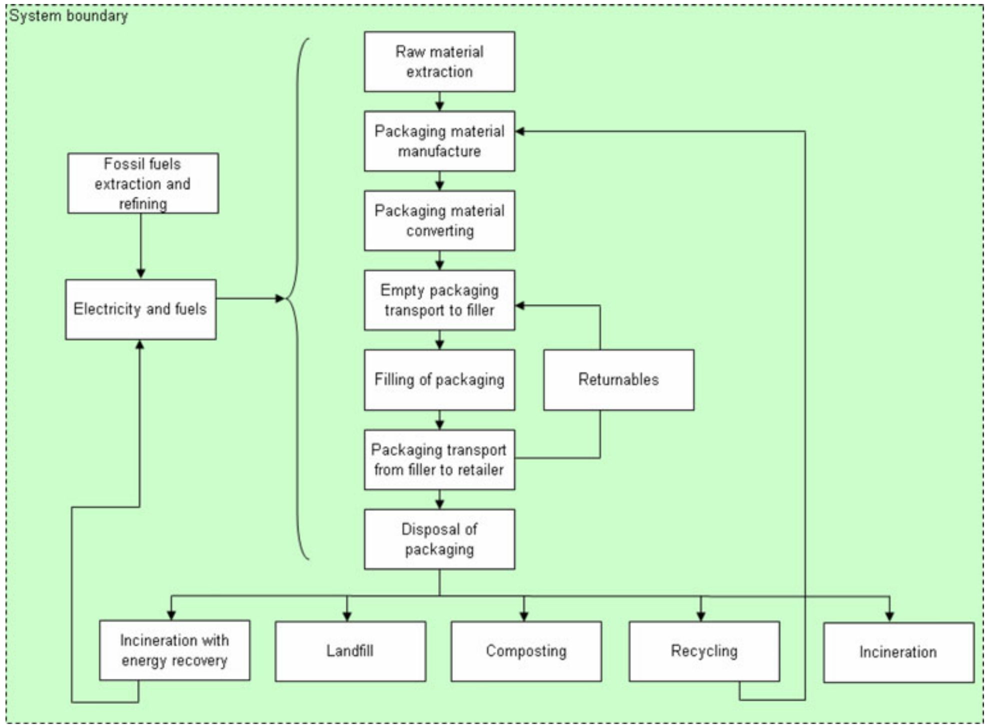
4.3 System boundary and treatment of recycling and recyclate

As stated above, the scope of the system boundary in PIQET is “cradle-to-grave” and is illustrated in Fig. 2.

As noted in Fig. 2, the approach to recycling and recyclate is accounted for at two points in the life cycle. Firstly, material production impacts take account of the use of recycled material in the production process. Secondly, waste impacts of a product are assumed to be affected when postconsumer packaging product is collected for recycling rather than being sent to landfill or some other waste disposal fate. Both open loop and closed loop recycling exist within the diverse material management practices associated with packaging across different materials, systems and geographies, and in configuring recycling credits, the principal of system boundary expansion was applied as far as possible within the constraints of approximation imposed by the speed and simplicity requirements of the tool (Fig. 3).

Recycled content is an important consideration in reducing the environmental impacts of packaging. Companies are encouraged to optimise the recycled content of

Fig. 2 System boundary of PIQET



their packaging materials. PIQET allows the user to vary the recycled content and therefore to analyse the changes in environmental impacts on account of having a packaging system with a lower or higher recycled content.

Recycled content includes both preconsumer and post-consumer material, as per ISO 14021 (ISO 1999). While it is ideal to strive for as much postconsumer content as possible, most packaging suppliers using recycled content cannot accurately define the proportion incorporated in their production.

Although determining the impact of a recycling process is relatively straightforward, allocating that impact to a packaging system can become difficult. The difficulty when allocating the benefits of recycling[2] comes about because recycling usually takes place in an ‘open loop’ process. That is, the waste materials collected from one life cycle system usually are reprocessed into other product life cycles. A difficulty then arises as to which product life cycle should be allocated the benefit of recycling: the donor life cycle or the recipient life cycle?

If all the benefits of recycling are allocated to the end-of-life of a packaging component, this would mean that any product that is designed for recycling at the end-of-life will be given a recycling benefit proportional to the amount of material that is recycled. This approach encourages packaging systems to be designed such that they are recycled at the end-of-life. It also meets the important test of ensuring that the benefits of recycling are only allocated once. A pitfall of this approach is that it ignores the use of recycled content in packaging. Packaging produced from 100% recycled material does not get a credit for recycling, because this is solely allocated to products based on how they are disposed of at the end of their lives.

For many materials, this allocation method potentially inaccurately states the true impacts of a product, especially when recycled materials are being used in manufacturing that would otherwise be expected to end up in landfill.

In order to make PIQET's allocation more balanced, an allocation approach has been developed that takes into account both ends of the product life cycle. Rather than allocating the benefits of recycling solely on the basis of disposal at the end-of-life, allocation will also be based on the use of recycled material in the production of the packaging product. When the user enters the amount of

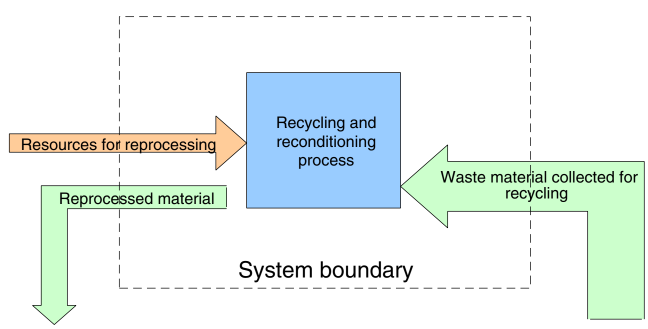


Fig. 3 Recycling in PIQET

[2] Recycling processes usually generate net environmental benefits; however, in some cases, they generate net impacts.

recycled material to be used in the packaging system (% PCR), this will be used in the calculation of life cycle impacts along with the percentage recycled (% recycled) at the end-of-life. This allocation methodology is developed so that no more than 100% of the benefit associated with recycling is allocated to the product life cycle. To achieve this end, half the benefit of recycling is allocated to the packaging system based on the % PCR content, and half is allocated based on the % recycled at the end-of-life, i.e. credit is distributed on a 50:50 basis—between the end-of-life and conversion steps.

4.4 Inventory analysis

The inventory of process information incorporated into PIQET was developed using the LCA software package SimaPro. Guided by input from the IAC, processes were constructed under the categories shown in Table 3 based on known packaging manufacturing and distribution practice in Australia. The processes constructed leveraged existing SimaPro material databases such as Australian LCI Database BUWAL, EcoInvent, ETH-ESU 96, IVAM and IDEMAT. Where process models were used that had been constructed from non-Australian data, they were regionalised by including regional specific background energy data. All processes were constructed within SimaPro using standardised units (e.g. all material processes were based on 1 kg of material), which allowed impact results to be subsequently combined to approximate the impacts of complex packaging systems across their life cycles.

Data quality presented a significant challenge. A core function of the tool is to provide a quick comparative assessment of packaging format options, which necessitates a degree of consistency across underlying LCI data. Given the wide range of sources, such consistency was not inherent and so had to be achieved through the customisation of available LCI information (primary data collection was considered outside the scope of the project). Such customisation was generally limited to the changes needed to achieve consistent geographical relevance, such as altering a European process inventory to incorporate regional energy data to suit regional conditions using 1% cutoff criteria for climate change indicator only. The choice of climate change indicator for customisation was based upon the premise that stakeholders in the packaging industry will continue to be subjected to climate change risks from various sources. Other data quality aspects such as completeness, representativeness and technology coverage were subjectively assessed; however, no formal data quality requirements were enforced, beyond geographical relevance. This allowed a wide range of LCI data to be included, adding to the tool's versatility, but potentially introducing the risk that data quality may not be sufficient to support the goal and scope of a specific user's application.

Table 3 Inventory categories used in PIQET

Life cycle stage	Description	Key data sources	Data quality
Materials	Impacts associated with the extraction of raw materials and production of a packaging material	A range of data sources, drawing on Australian life cycle inventories (Australian LCA Database), as well as adapted international databases such as BUWAL250, Eco-Invent, IVAM, IDEMAT, Franklin and ETH-ESU	A range of data quality is achieved across the inventories. In general, inventories have been developed to reflect regional geography. Other data quality indicators vary between materials.
Converting	Impacts associated with the conversion of a packaging material into a packaging component	A range of data sources, drawing on Australian life cycle inventories (Australian LCA Database), as well as adapted international databases such as BUWAL250, Ecoinvent, IVAM and IDEMAT	A range of data quality is achieved across the inventories. In general, inventories have been developed to reflect regional geography. Other data quality indicators vary between processes.
Transport	Transportation-related impacts, including fuel consumption, emissions and other consumables	Transport models are based on Australian life cycle inventories. Fuel consumption and backhaul utilisation is based on national average data.	Australian sources relating to average technology, and average practice. Generally, representative datasets are produced in a consistent manner.
Filling	Filling impacts based on consumption of water, electricity and natural gas of the packaging line	Regional (actual and customised) life cycle inventories for the provision and consumption of electricity, water and natural gas	Regional sources relating to average technology, and average practice. Generally, representative datasets are produced in a consistent manner.
Waste disposal	Impacts related to the processing and disposal of packaging material at the end of its life	Australian life cycle inventories (Australian LCA Database) based on studies of waste disposal practice in Australia	Australian sources relating to average technology, and average practice. Generally, representative datasets are produced in a consistent manner.

As PIQET development continues, two strategies are being applied to address potential data issues. The first involves seeking to improve the quality of the underlying LCI data through local research and the incorporation of improved publicly available LCI data. The second approach involves educating users to incorporate data quality into decision-making frameworks, and thus address the perennial problem of data quality in the same manner as the ISO14040 standard.

The current PIQET database has data for life cycle stages occurring for Australia, China, Japan, New Zealand, USA and Western Europe. This allows users to customise and model different life cycle stages, from the cradle to the grave, occurring over six geographical regions.

4.5 Impact assessment

Life cycle impacts were assessed across eight indicators shown in Table 2. The indicators were chosen based on the quality of data available for the packaging processes incorporated in the inventory, and the needs of brand owners, as articulated by the IAC.

Impact assessments were undertaken for each of the packaging processes developed in SimaPro under the categories described in Table 3. These results were then organised into a dataset based on the standardised units created for each process category: the Impact Assessment Database (IAD). Impact assessment of a packaging system within PIQET is achieved by combining the results in the IAD, based on the standardised units established and data collected by the user regarding the packaging system's mass, material, transport, etc. A vector of impacts associated with a packaging system is determined by PIQET by multiplying the relevant standardised impact assessment elements in the IAD by the associated PIQET input parameters, and then totalling the impact. The result is an impact assessment for the packaging system that incorporates impacts associated with each stage of the life cycle.

4.6 Development of the interface

A major challenge in the development of PIQET was creating a user interface that would collect the information necessary to undertake a detailed assessment while, at the same time, being relatively easy to use. As the assessment information requirements evolved, it became clear that input requirements fitted neatly into the notional stages of a packaging system life cycle. Building on this approach, a series of ‘Storyboards’ were developed that were presented in sequence to the user, each requesting packaging information associated with a stage of the packaging system life cycle.

Initial development was undertaken using a MS Excel-based prototype that was issued to the IAC for review and comment. Having developed to a point where feedback from the IAC had stabilised, the prototype PIQET was translated into a web-based version. Translation to the web allowed for distribution and testing of the tool amongst a wider audience, allowing further iterative design refinement.

4.7 Results generated

Making the output results of PIQET understandable to technologists and designers, who may not be familiar with LCA, also presented a challenge for the project. In general, industry partners sought to simplify results and would have preferred PIQET to generate a single score for a packaging system. A single score was not pursued, as there is currently no agreed method to weight environmental impacts within the packaging supply chain. Instead, impact assessment results are presented as characterisation values allowing the user to undertake interpretation based on his/her priorities. PIQET also enables packaging systems to be compared, whereby the user creates packaging system ‘scenarios’. Wherever possible, results are presented graphically and are supported by more detailed tables.

Figure 4 shows an example chart that presents cumulative energy demand impacts of a packaging system, identifying the levels of the packaging system and the stages of the life cycle that cause the impact. Negative impact values infer net benefits (in this case, the packaging system is being recycled at the end of its life, hence the negative impact of waste).

Another example of graphical presentation in PIQET is the use of a ‘spider diagram’ to present comparative LCA results. The spider diagram shown in Fig. 5 presents a comparison of three different packaging system formats against five different user-selected impact indicators. PIQET automatically normalises the results so that the axis for each parameter extends to the highest scored result. The users can plot all eight environmental impact indicators or select a smaller number depending upon their internal priorities. The format plotted at the outer edge of each nominated environmental impact indicator has the highest impact for that indicator.

Although normalisation is used to construct the spider diagram, it retains the integrity of the separate indicators that can still be interpreted individually by the user. It was acknowledged that a spider diagram constructed in this manner inferred a unitary weighting of impacts; however, this shortcoming was considered secondary to the clarity it brought to packaging system comparison, especially where differential improvement was being sought. Logically, where users wish to prioritise considerations of some impacts over others, the area of the spider should not be used. Also, the absolute values of each axis should be noted since, in different cases, they can be relatively small in a

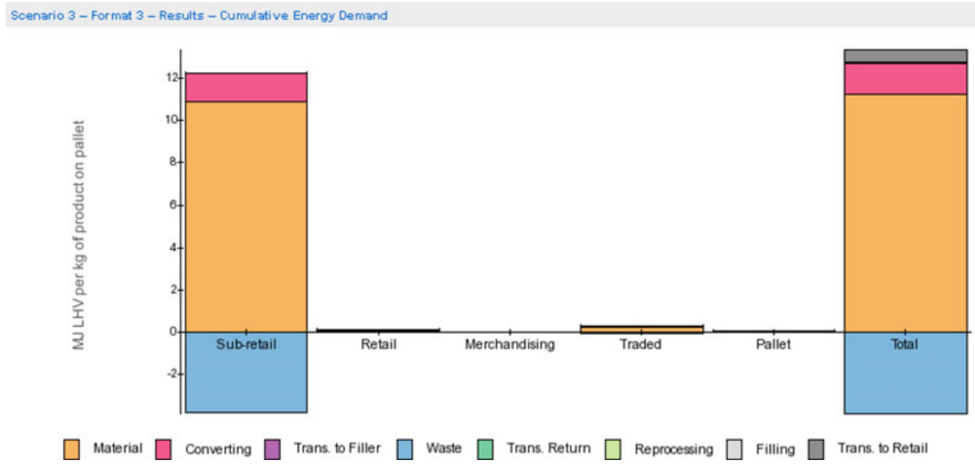


Fig. 4 Example of graphical presentation of impact assessment results

given location/context, with a slight absolute variation indicating a large relative variation on the axis. These issues, combined with the appropriate selection of 3–8 impact parameters, indicate the considerations applying to spider diagram results interpretation and the need for reference to the tables of results.

5 Limitations

In general, PIQET has been designed to provide users with qualified quantitative information concerning the environmental performance of packaging systems. Since data and assumptions limit modelling options to 'typical' process scenarios associated with materials, converting, transport, filling and disposal, the tool cannot reflect accurately the unique aspects of a particular process. While this is a limitation, the functionality in PIQET does allow the user to test sensitivities and variables that can highlight life cycle 'hot spots' (i.e. the processes that contribute the most to the overall impacts). This feature provides the user with the ability to understand where to focus data collection.

Determination of environmental impacts associated with both (1) the use of recycled materials in packaging manufacture and (2) the recycling of packaging at the end of its life presents a particular challenge in PIQET. Although, in many cases, recycling of packaging materials is seen to generate net environmental benefits, determining which life cycle (donor or recipient) should receive these benefits becomes problematic. This issue is not uncommon in LCA, and many methods have been developed to address it. In PIQET, an arbitrary 50% weighting of recycling benefits associated with incorporation of recycled content and a 50% weighting of recycling benefits at end-of-life have been applied. The method provides reasonable directional feedback to packaging system designers and avoids double counting of recycling credits; however, the approach is arbitrary and, as such, is a departure from the

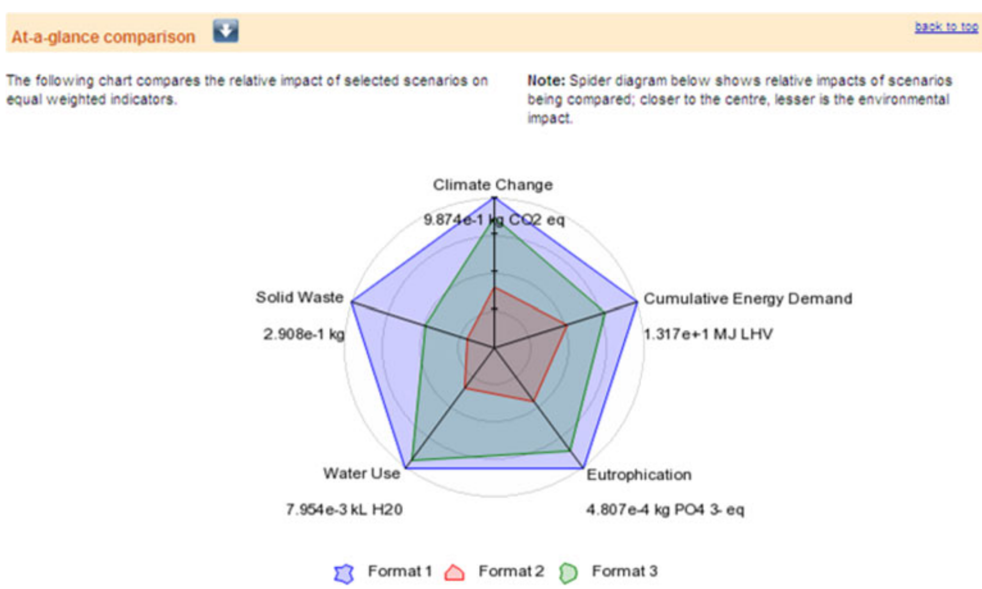


Fig. 5 Spider diagram example

ISO14040 (LCA) series of standards. It is recognized that many good methods exist for tackling the issue that could better reflect consequential environmental impacts; however, implementation within the PIQET software framework has, to date, been difficult due to a technical requirement that one method be used for all materials. New features are currently being developed to move away from this arbitrary allocation key to one based more closely on the unique circumstances of each material and/or the relevant regulatory or standards being considered by the user.

Data availability and quality are always challenging for LCA practitioners. The data supporting PIQET results are subject to similar constraints to ensure consistency with the defined goal and scope for PIQET. The embedded life cycle inventory database within the tool is updated on a regular basis.

A further limitation in PIQET is in the quick interpretation of results. While the ‘spider diagram’ approach promises a quick reference ‘ready reckoner’ results screen for life cycle comparison of packaging systems, it also contains inherent shortcomings in terms of implied equal weighting of impact categories, appropriate selection of impact categories and scaling within impact categories through the use of normalised axes. Hence, such result outputs must be carefully interpreted, and training is important for all PIQET users to emphasise and illustrate appropriate interpretation. Upskilling of all users in life cycle thinking and interpretation is therefore critical to the appropriate use of PIQET results. Workshops and training sessions are conducted regularly to further their understanding of LCA and PIQET's application within their organisation.

Clearly, PIQET is not a replacement or substitute for full LCA, nor can results it generates be considered as more than indicative and conditional. Specifically, PIQET is not intended to be used in product declarations or communications where the limitations and context of PIQET may be obscured or overlooked. Where PIQET can be useful is in providing quick feedback through a design process, allowing LCA techniques to be incorporated in situations where resources may not extend to full detailed LCA studies. Its strength and application lie in dissemination of life cycle thinking and environmental metrics, and their use in packaging design and decision-making processes within and across actor groups in consumer packaging production and retailing organisations.

6 Dissemination and application

PIQET is designed to address a gap in the eco-design and environmental innovation process as it relates to packaging systems. This gap is the lack of availability of low cost, readily accessible, first-point information and knowledge regarding the indicative comparative environmental impacts of alternative packaging systems being considered for adoption at the design stage. It follows that PIQET has been designed to facilitate training and knowledge development around life cycle concepts, while also providing information for use between actors on the supply side, both within organisations and across production and retailing supply chains.

The tool has proved valuable in this regard to a range of organisations as part of the packaging design process. Its use at the design stages enables environmental impacts to be considered up-front and environmental improvements made. It is particularly suited to continuous improvement and benchmarking against different designs.

Some subscribing companies have mandated the use of PIQET at defined points in their new product development (NPD) processes to assess new or modified packaging formats, or benchmark against competitors. Any increase in an environmental impact indicator triggers redesign, and/or special consideration before further development can proceed. For example, at one brand owner organisation, an anonymous PIQET subscriber described the reason for using PIQET to one of the authors in the following terms: ‘The goal is to ensure that the environmental performance of the new or redesigned packaging system is at least equal, if not better than the existing format’.

PIQET is also being used in environmental risk assessments. Packaging portfolios are scanned for poorly performing packaging systems (e.g. overpackaging, nonrecyclable systems, etc.). Systems are assessed and redesigned to continuously improve the environmental impact of the overall packaging portfolio, to maintain sales and reduce risk of any negative (e.g. media, regulatory) exposure.

In future, the design for environment (DfE) transition may partly depend on the ability of organisations to change decision-making criteria early in design processes, and to access information upon which to make such early decisions. Notwithstanding the substantial limitations of organisations in managing change, the extent of change required and achievable, and the myopic tendencies of ‘change from within’ processes, PIQET provides an early attempt to facilitate provision of early information, balancing ease of use and accuracy, robustness and reliability. This balance inevitably varies by sector, organisation and application.

7 Conclusions

While streamlined LCA tools represent a compromise in assessment accuracy, provided limitations are transparent and appropriate, the potential exists in driving uptake of concepts, knowledge and information about life cycle impacts across decision-making environments and change processes. In this

regard, streamlined LCA tools occupy a different position in the innovation niche of sustainable development processes to that of detailed LCA. While the latter is focused on providing accurate and detailed information, for example, for use in product declarations, the former occupy a more preliminary and 'first estimate' position. In this regard, the potential of streamlined tools such as PIQET is in reaching 'up' the design process to the parts that 'full' LCA cannot reach—initial conceptual stages where many important 'locking in' decisions may be made.

In order to achieve this, streamlined LCA tools, which are to be used in voluntary situations in market competitive systems, must be sufficient in differentiating between key environmental performance indicators across comparisons of presented options, and they must be sufficiently attractive, easy to use and valuable in cost–benefit terms to user organisations. In this paper, we have discussed the design, development, functionality and limitations of PIQET, a streamlined LCA tool, and we note that this tool is now being adopted by a range of organisations, including design, packaging manufacturers, brand owner and retail companies. The development and dissemination of PIQET have brought the environmental impact assessments of packaging materials and packaging life cycle stages to the fingertips of packaging technologists, designers, environmental managers and marketers. In as much as this leads to a greater awareness of the environmental impacts of material selection and packaging system design and packaging, there is potential for PIQET to be used to assist in industry change along less unsustainable lines.

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